ASSESSMENT OF ECOSYSTEM INTEGRITY OF LOWLAND DIPTEROCARP FOREST ECOSYSTEM USING REMOTE SENSING

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"Praise to Almighty Allah, Alhamdulillah for all He granted"

My beloved mother, Azizah Setia

My beloved father, Abdul Razak Idris

My beloved wife, Asyikhin Zainal

My beloved son, Muhammad Adrean Eusoff

Family and friends

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ABSTRACT

Ecosystem Integrity Index (EII) is a concept to determine the quality or the health of an ecosystem. The EII development can assist forest managers and decision makers in the conservation effort and forest management in Malaysia through the development of a simple and easy-to-adopt index. The aim of this study is to assess and evaluate the EII through the development of forest structure empirical models from remotely sensed data for lowland dipterocarp forest in Malaysia. The objectives of this study are: (i) to assess the structure and composition of lowland dipterocarp forest in Malaysia, (ii) to develop empirical model for estimating stand structure from remotely sensed data, and (iii) to derive the ecosystem integrity index for lowland dipterocarp forest. Tree Basal Area (BA), aboveground biomass (AGB) and volume plot from plot data were used as dependent variables, while remote sensing data from Landsat, Pleiades and LiDAR were used as independent variables for model development. Tree plot census was carried out from 17 to 19 May 2016, while remote sensing data acquisition dates for Landsat, Pleiades and LiDAR were 13 March 2016, 24 January 2015 and April 2015 respectively. Forest Structure Modeling was carried out by means of a correlation analysis with the calibration of dependent and independent data to select the most significant and accurate remote sensing variables to derive empiric equation (model), fitting stage to select the best model with the highest coefficient of determination (R^2) and the lowest root mean square error (RMSE) validation of the final selected. The Ecosystem Integrity Index was developed by the average percentage of the predicted BA, AGB and model volume. The EII was categorised at five integrity levels as high (81–100%), medium high (61–80%), moderate (41–60%), medium low (21–40%) and low (0–20%). A total of 1035 trees with diameter at breast height (DBH) of 5.0 cm and above were recorded in 69.115 ha sampling areas. The total trees recorded represented 150 species from 87 genera and 34 families. *Shorea macroptera* (Dipterocarpaceae), *S. leprosula* (Dipterocarpaceae) and *S. parviflora* (Dipterocarpaceae) are three dominant species, with Species Important Value Index

(SIV*i*) of 6.49%, 6.23% and 5.51%, respectively. Dipterocarpaceae is the most dominant with Family Important Value Index (FIV*i*) of 33.54%. The developed final model is robust and consistent with high R^2 with range of 0.84 to 0.87. The final models constructed for AGB, BA and volume value of R^2 are 0.85, 0.84 and 0.87 respectively. The RMSE of AGB, BA and volume model are 53.1 Mg/ha, 3.54 m^2/ha and 46.4 m^3/ha, respectively. The overall stand AGB, BA and volume for Sungai Menyala Forest Reserve is 282.29 Mg/ha, 17.68 m^2/ha and 239.51 m^3/ha. An Ecosystem Integrity Index (EII) assessment has been successfully demonstrated by this study with production of practical, multi-scaled, flexible, adjustable and policy-relevant index. The overall EII of Sungai Menyala Forest Reserve is in Category 3, which shows that the area is within the medium value.

ABSTRAK

Indeks Integriti Ekosistem (EII) merupakan satu konsep untuk menentukan kualiti atau kesihatan sesuatu ekosistem. Penghasilan EII boleh membantu pengurus hutan dan pembuat keputusan dalam usaha pemuliharaan dan pengurusan hutan di Malaysia melaui penghasilan indeks yang praktik dan mudah diterima pakai. Tujuan utama kajian ialah membuat pentaksiran dan penilaian EII melalui penghasilan model empirikal struktur hutan daripada data penderiaan jauh hutan dipterokarpa tanah rendah di Malaysia . Objektif kajian ialah: (i) Menilai struktur dan komposisi hutan dipterokarpa tanah rendah di Malaysia, (ii) Menghasilkan model empirikal untuk menganggarkan struktur hutan menggunakan data penderiaan jauh, dan (iii) Memperoleh indeks integriti ekosistem untuk hutan dipterokarpa tanah rendah. Luas pangkal (BA), biojisim atas tanah (AGB) dan isipadu pokok daripada data plot digunakan sebagai pemboleh ubah bersandar manakala data penderiaan jauh daripada Lansat, Pleiades dan LiDAR digunakan sebagai pemboleh ubah bergerak balas dalam penghasilan model. Bancian pokok telah dijalankan pada 17 hingga 19 Mei 2019 manakala tarikh pemerolehan data penderiaan jauh untuk Landsat, Pleiades dan LiDAR ialah 13 Mac 2016, 24 Januari 2015 dan April 2015 masing-masing. Pemodelan struktur hutan dilakukan dengan analisis korelasi dengan penentukuran data pemboleh ubah bersandar dan pemboleh ubah bergerak balas untuk pemilihan pemboleh ubah penderiaan jauh yang paling signifikan dan tepat untuk menghasilkan persamaan empirikal (model), proses pemadanan dilakukan untuk memilih model terbaik yang mempunyai nilai pekali penentuan (R^2) yang tinggi dan nilai punca min ralat kuasa dua (RMSE) yang terendah untuk model akhir. Indeks Integriti Ekosistem (EII) dihasilkan berdasarkan peratusan purata BA, AGB dan isipadu model. Kategori EII berpandukan lima tahap integriti iaitu tinggi (81–100%), tinggi sederhana (61–80%), sederhana (41–60%), sederhana rendah (21–40%) and rendah (0–20%). Sejumlah 1035 pokok dengan diameter di paras dada (DBH) 5.0 cm ke atas direkodkan di 69.115 ha keluasan pensampelan. Jumlah dirian pokok yang direkodkan mewakili 150 spesies daripada 87 genera dan 34 famili. *Shorea macroptera* (Dipterocarpaceae),

S. leprosula (Dipterocarpaceae) dan *S. parviflora* (Dipterocarpaceae) merupakan spesies yang dominan dengan nilai indeks kepentingan spesies (SIV*i*) masing-masing sebanyak 6.49%, 6.23% dan 5.51%. Dipterocarpaceae merupakan famili yang dominan dengan nilai kepentingan famili (FIV*i*) sebanyak 33.54%. Model akhir yang dihasilkan adalah teguh dan konsisten dengan pekali penentuan (R^2) yang tinggi dalam julat 0.84 hingga 0.87. Model yang dihasilkan untuk biojisim atas tanah (AGB), luas pangkal (BA) dan isipadu menunjukkan R^2 0.85, 0.84 dan 0.87 dengan nilai punca min ralat kuasa dua (RMSE) 51.1 Mg/ha, 3.54 m^2/ha dan 46.4 m^3/ha masing-masing. Nilai keseluruhan dirian AGB, BA dan isipadu di Hutan Simpan Sungai Menyala ialah 282.29 Mg/ha, 17.68 m^2/ha dan 239.51 m^3/ha. Kajian ini telah membuktikan penilaian EII boleh dilakukan dan menghasilkan index yang mudah, pelbagai skala, fleksibel, boleh laras dan sesuai dengan polisi. Keseluruhan EII di Hutan Simpan Sungai Menyala mencatatkan kategori ke-3, yang menunjukkan kawasan ini di dalam nilai yang sederhana.

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LIST OF ABBREVIATIONS

AGB	-	Aboveground biomass
BA	-	Basal area
DBH	-	Diameter at breast height
EII	-	Ecosystem integrity index
GIS	-	Geographic information system
HVCF	-	High value conservation forest
IBI	-	Indices of biotic integrity
IHN	-	Inventori hutan national
JPSM	-	Jabatan Perhutanan Semenanjung Malaysia
LiDAR	-	Light detection and ranging
MAPE	-	Mean absolute percentage error
NFC	-	National forest council
NFP	-	National forest policy
PFR	-	Permanent forest reserve
RSO	-	Rectified skew orthomorphic
RMSE	-	Root mean square error
USGS	-	United States Geological Survey
VFR	-	Virgin forest reserve

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LIST OF PUBLICATIONS

Journal:

(i) Muhammad Azmil, A. R., Mohamed, M., Alona, C. L., Hamdan Omar, & Muhammad Afizzul Misman. (2018). Tree Species Richness, Diversity and Distribution at Sungai Menyala Forest Reserve, Negeri Sembilan. *IOP Conference Series: Earth and Environmental Science*, *269*, 012003. https://doi.org/10.1088/1755-1315/269/1/012003

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(i) Linatoc, A. C., Mohamed, M., & Muhammad Azmil A.R. (2017). Rate of Mangrove Regeneration at Tanjung Piai After The Establisment of Wavebreaker Bunds. In *Report on Habitat and Ecological Research After Wavebreaker Project at Tanjung Piai Johor National Park (Vote 29106)* (pp. 13–31).

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(ii) Muhammad Azmil, A. R., Mohamed, M., C L Alona, Hamdan Omar, & Muhammad Afizzul Misman. (2018). Tree Species Richness, Diversity and Distribution at Sungai Menyala Forest Reserve, Negeri Sembilan. In *International Conference on Biodiversity (ICB) 2018*. UTHM (Pagoh).

CHAPTER 1

INTRODUCTION

1.1 General background

Deforestation activity is a big issue and has been highlighted by the local community, non-governmental organizations (NGOs), and stakeholders in Malaysia. This activity has been reported to be one of the major causes of the decreasing biological diversity and the destruction of the natural ecosystem in Malaysia. From 2007 to 2016, 213,400 ha of forest area in Malaysia had been logged. It has also been recorded that 21,698 ha forest area is logged annually, which is about 0.38% of total forest area in Malaysia (Omar & Misman, 2018).

Human activities are the direct causes of deforestation in Malaysia. Lowland forest deforestation in Malaysia is mainly caused by the expansion of agricultural areas. Large forest areas have been converted into oil palm and rubber plantations at commercial scales, hydroelectric dams, reservoirs, as well as quarry and mining sites (Manokaran *et al.*, 1992; Omar & Misman, 2018).

Forest conversion for development cannot be avoided in a developing country such as Malaysia. However, this activity must be done in a sustainable manner to ensure forest health. A healthy forest can be determined by the continuous supply of forest products and services while at the same time maintaining to stress and disturbance (Trumbore, Brando, & Hartmann, 2015). There is a need to find a way of monitoring the effect on the recovery process toward forest health. This study proposes the ecosystem integrity index as one of the options to address this problem.

Ecosystem integrity (EI) is defined as "the ability of an ecosystem to support and maintain a balanced, adaptive community of organisms having a species composition, diversity and functional organization comparable to that of the natural habitat of a region" (Reza & Abdullah, 2011; Brown & Williams, 2016). This means that an ecosystem with good integrity exhibits of good ecosystem health, resilience, and the capacity of self-organizing (Reza & Abdullah, 2011).

The Ecosystem Integrity Index (EII) is the evaluation of the status of a specific ecosystem, refer to an optimal condition that must be established for the ecosystem (Blumetto *et al.*, 2019). The idea of EII development was based on the meaning of the "ecosystem" itself. An ecosystem is the interaction of complex physical, chemical, and biological components in a community. Maintaining the equilibrium of these components will result in a healthy ecosystem, which means that the community has good integrity (Reza & Abdullah, 2011; Zhang, Yang, & Singh, 2014). Several indicators have been developed to describe the condition of the ecosystem.

The indicators are used to identify potential environmental problems and facilitate the construction of regulations by policy makers. These indicators could be used in the measuring and monitoring of the EII through an ecological assessment by forming an ecological score with a multimetric index that intends to assess the ecosystem's structure, composition, diversity, and function organization (Andreasen *et al.*, 2001; Brown & Williams, 2016).

Remote sensing is a technique of determination of physical data of an object using a sensor without direct contact with the object itself (van der Meer *et al.* 2010). In ecological studies, the environmental indicators that detected by remote sensing sensors provide quantitative estimates of the ecosystem characteristics. This technique was applied towards the forest management and conservation by the estimation of watershed area, natural vegetation cover, buffer area degradation, biomass change, invasive species, water turbidity and chlorophyll concentration (Klemas, 2013). The remote sensing was used for forest ecosystem monitoring since the 70s during the launch of the Landsat satellite (Irons *et al.* 2012). Since then, this technology has been updated by enhancement of satellite sensors to increase their accuracy and development of spectral indices that usefull on the prediction of the forest structure. LiDAR is one of the latest development of remote sensing technology that recently has been used in forestry works. This technology has shown the accurate on canopy heights, stand volume, BA and AGB estimation (Dubayah & Drake, 2000). The integration of remotely sensed data with actual plot data has been considered for EII assessment because of the cost-effective factor that allows for prolonged observation in a wide forest area. The high accuracy of forest stand parameter estimation by remote sensing technique is also one of the reasons why forest managers use this method in forest biomass monitoring (Moran *et al.*, 2004; Klemas, 2013).

Before the development of the index of ecosystem integrity, the Biotic Integrity Indices (IBI) were used to examine the effect of stressors on biotic communities. This index was widely used in the assessment and monitoring of the previous study using a similar method, but the reach was confined to aquatic ecosystems, especially rivers (Jordan & Pauline A. Vaas, 2000; Johnston *et al.*, 2011). Furthermore, this index only focused on freshwater habitats by using the indicator that can only be found in the aquatic ecosystem, resulting in the unsuccessful implementation of the index for terrestrial plant community evaluation (LaPaix *et al.*, 2009). The index developed in this study will take the indicators in the terrestrial ecosystem into account to establish a suitable index for terrestrial ecosystems. Thus in this study, the development of terrestrial community EII could estimate the actual condition of the community.

The EII assessment for this study uses actual ground data and produces an integrity map for the whole map area. This assessment will postulate the forest stand parameters correlated to the remotely sensed data. The study area and the forest stand parameters can also be analyzed by the integrity map produced by this study. This study uses three sources of remotely sensed sensors which are Landsat, Pleiades, and LiDAR, with the assumption that integration would give an accurate result because each of the sensors has their own strength in estimating the forest stand structures.

1.2 Problem statement

Several issues are related to the development of EII by using remotely sensed data in lowland dipterocarp forest in Malaysia. These issues can be generalized into three major groups, which are (i) updating the plant community structure and diversity of Sungai Menyala Forest Reserve, (ii) improving forest monitoring towards remote sensing assessment, and (iii) applying remote sensing in the EII assessment can be used to help the stakeholders such as forest managers and policy makers understand its outcome.

Sungai Menyala Forest Reserve has been gazetted as a forest reserve since 1950 after undergoing selectively logged activity (Manokaran & Kochummen, 1987). This forest is still in the regeneration phase and is managed by the Negeri Sembilan

Forestry Department. The activities in this area are limited for study purposes. However, the latest documentation on the tree species composition in this area was done by Manokaran & Kochummen in 1987 and there is no current update in this aspect. This documentation activity is crucial in showing the effectiveness of forest management for this forest reserve.

The conventional method of forests monitoring is costly, requires high labor force and longer periods of observation. It has been estimated that a traditional sampling of plots requires 6 to 8 hours of work and 8 man power (Fletcher *et al.*, 2002). It has been shown that 616 plots were established in Inventori Hutan Negara 5 (IHN-5) and the project has been completed in 3 years of monitoring. By contrast, using remote sensing data, the current study successfully demonstrated a robust and high-precision estimation of the forest structure using only 39 plot data. The current study had proven that by using the remote sensing technique, the number of plot establishment is reduced thus minimized the number of labor.

Forest structure estimation assessment by using remotely sensed data to a complex forest structure such as the tropical forest in Malaysia is challenging. The specific characteristic of the forest area is also one of the difficulties in forest stand estimation (Lu, 2005). However, this matter can be overcome by using remotely sensed data that have high accuracy toward forest structure estimation such as LiDAR that was used in this study. This problem can also be resolved by remotely sensed data integration. This study integrates three types of remotely sensed data which are Landsat, Pleiades, and LiDAR. By integrating these data, the study enhances the model performance on the forest structure estimation, which would be a better assessment compared with the previous study that used a similar approach but limited to only single remotely sensed data for the estimation (Bouvier, *et al.*, 2015; Wallner, *et al.*, 2015).

The general public, especially forest managers and decision makers, do not have technical background in forestry. It is hard to make them realize the absolute value of preserving a healthy forest environment (Reza & Abdullah, 2011). Thus, this issue can be assisted by the development of the Ecosystem Integrity Index. Ecosystem Integrity assessment is a multi-metric index in the form of an ecological score of ecological structure, function, composition, diversity and functional organization (Brown & Williams, 2016). The theory of ecological integrity acts as an analogy for biological diversity, in that ecological integrity is defined to be "the ability of the ecological environment to sustain and preserve a population of organisms with species distribution, abundance and functional structure similar to that of natural ecosystems". This concept clearly means that an individual site with a high ecological integrity score may mean to contain a standard biota collection and abundance for the habitat form of the site. The EII assessment that established from this study can be interpreted by the general public and decision makers by evaluating the integrity factor or percentage of the index.

The original Biotic Integrity Indices (IBI) defined the integrity of 12 metric streams representing the health, reproduction, structure and abundance of fish species. The parameter was scored by comparing the measured values with the predicted values under comparatively unimpaired (reference standard) conditions, and the scores were aggregated into the overall score. The IBI is too concentrated on the aquatic ecosystem and can not be adapted to the terrestrial climate, which encourages the development of an overall terrestrial EII. The current study assessed the quantitative data from the tree DBH and height from the field plot. The field data will be calculated for the three variables of BA, AGB and volume and being integrated with remote sensing data to make a forest structure model prediction to explain the forest condition of the study area. The suggested forest condition could be an excellent component of the EII variables since the data used the native species in the ecosystem.

The development of EII in this study could indicate the magnitude and direction of changes with the account of the ecological and biological phenomena at relevant organization level and spatial–temporal scale. The EII that developed in this study can evaluate the terrestrial ecosystem condition in lowland dipterocarp forest.

1.3 Research questions

Having all issues and problems stated above, the following research questions were developed:

(i) Could remotely sensed data be applied to assess the Ecosystem Integrity Index of dipterocarp forest ecosystem?

(ii) What is the best empirical model to estimate the basal area, aboveground biomass, and volume from remotely sensed data?

(iii) Do the basal area, aboveground biomass, and volume variables in plot data and remotely sensed data give high accuracy on the forest structure estimation model?

(iv) Could the combination of basal area, aboveground biomass, and volume variables be used to develop the forest structure empirical model and hence be proposed in the Ecosystem Integrity Index assessment?

1.4 Aim and objectives

The aim of this study is to assess and evaluate the Ecosystem Integrity Index through the development of forest structure empirical models from remotely sensed data for lowland dipterocarp forest in Malaysia. The specific objectives are as follows:

(i) To assess the structure and composition of a lowland dipterocarp forest in Malaysia.

(ii) To develop empirical models for estimating stand basal area, aboveground biomass, and volume from remotely sensed data.

(iii) To derive the Ecosystem Integrity Index for lowland dipterocarp forest in Malaysia.

1.5 Scopes of the study

This study was conducted to assess the Ecosystem Integrity Index (EII) for the tropical forest. This study only covers the lowland dipterocarp forest areas and the assessment was done specifically in the Sungai Menyala Forest Reserve area. Sungai Menyala Forest Reserve was chosen as the subject of the forest structure empirical model and EII development because it is a representation of a lowland dipterocarp forest in Malaysia. Sungai Menyala Forest Reserve is classified as a lowland dipterocarp by Symington, (1943). The EII is developed for the lowland tropical forest because this forest type has the highest forest cover in Malaysia. However, no recent evidence shows that Sungai Menyala Forest Reserve is still showing this characteristic. Thus, this study will analyze the plot data in Sungai Menyala Forest Reserve to verify if it still shows the Dipterocarpaceae family dominance so that the developed empirical

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